

Florida Phosphate Mine Pilot Study Aerial Radiological Survey

U.S. Department of Energy
National Nuclear Security Administration
Remote Sensing Laboratory (RSL)



RSL - Andrews



RSL - Nellis

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The work presented in this talk was supported by the U.S. DOE NNSA Nevada Operations Office and was conducted at their Remote Sensing Laboratory, located in Las Vegas, NV, which is maintained and operated by Bechtel Nevada (BN).

The Remote Sensing Laboratory mission is to provide a broad range of scientific, technological, and operational disciplines with core competencies in Remote Sensing, Emergency Response Operations and Support, and Applied Science and Technologies in support of radiological incident response.

Aerial Measuring System (AMS) assets are located at Nellis Air Force Base in Las Vegas, Nevada and Andrews Air Force Base outside of Washington DC.

The AMS fleet consists of three B200 fixed-wing and two Bell-412 helicopter rotary-wing aircraft. One fixed-wing and one helicopter rotary-wing aircraft are stationed at RSL-Andrews. For the Florida survey, the helicopter will be deployed from the RSL-Andrews facility.

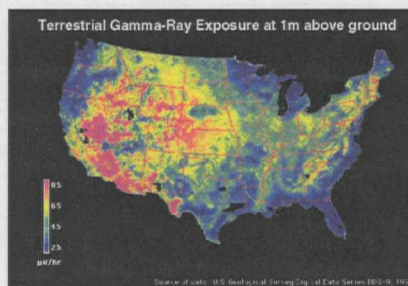


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Prior Baseline Radiological Surveys

National Uranium Resource Evaluation (NURE) Program

- 1970s to early 1980s the United States Government sponsored aerial radiometric and aero-magnetic surveys over the entire United States
- Purpose of the program was to identify GENERAL regions with potential for mining uranium
- In 1981, EG&G Geometrics flew a fixed-wing aircraft equipped with an array of sodium iodide scintillation detectors over the north central region of Florida
- Survey Flight Parameters
 - Altitude: 500 feet
 - Line Spacing: 6 miles
- Data collected sampled only 3% of the over-flown area
- Previous studies in Florida and elsewhere have utilized the NURE data effectively to define WIDE AREA radon potential but in no way does the NURE data approach the sensitivity, spatial resolution, and 100% areal coverage as proposed by the Pilot Study Aerial Radiological Survey.



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This image was generated from NURE aerial gamma-ray data presented in **United States Geological Survey Digital Data Series DDS-9**, "National Geophysical Data Grids: Gamma-Ray, Magnetic, and Topographic Data for the Conterminous United States", by J.D. Phillips, J.S. Duval, and R.A. Ambrosiak, 1993. [<http://energy.cr.usgs.gov/radon/DDS-9.html>]

The primary source for aerial radiometric data in the United States is reports from the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program of the 1970s and early 1980s. These data have been integrated into contour maps of equivalent uranium, thorium, potassium, and total gamma radioactivity exposure for the conterminous United States.

Aerial gamma-ray data can be used to quantify and describe the radioactivity of rocks and soils. The majority of the gamma-ray signal is derived from the upper 20-25 cm (8-10 inches) of surficial materials (rock or soil). A gamma-ray detector is mounted in an aircraft that is flown over an area at a certain altitude, usually 120-150 m (400-500 ft). Equivalent uranium (eU) is calculated from the counts received by the gamma-ray detector in the energy window corresponding to bismuth-214. This technique assumes that uranium and its decay products are in secular equilibrium. A contour map of eU is then produced for the area. The same technique is used to estimate potassium (K), from the K-40 energy window, and equivalent thorium-232, from the thallium-208 energy window. Total gamma exposure can be estimated by combining the data from the potassium, uranium, and thorium data channels. More than 1.1 million line-miles of aerial radiometric data, using an array of sodium iodide scintillation detectors, and aero-magnetic data, using a magnetometer with a sensitivity of 1/4 gamma, were collected.

Prior Baseline Radiological Surveys

Florida Department of Health (FDOH) Historical Data

- Data collected as part of a FDOH monitoring program conducted from mid-1970's to mid-1990's
- Shows a wide variation in exposure background levels generally ranging from 6 to 50 $\mu\text{R/h}$ with some levels approaching 100 $\mu\text{R/h}$.
- Majority of data was collected from residential subdivisions but data was also available for two commercial sites.
- Preliminary review of the data was conducted and found to be very informative. Several residential areas were noted and their geographic locations were marked for further study.

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While the detailed distribution of activity in Florida is not presently known, existing Florida data and data from a similar survey series suggests that the distribution is probably more nearly represented by small areas of elevated activity rather than uniform distributions of small variability.

There are two Florida data sets which seem to support the small area hypothesis. One survey data set (compiled by numerous agencies from the 1970s through 1990s), consisted of targeted measurements made in relatively small sub-divisions, which found indications of exposure levels often exceeding 50 $\mu\text{R/h}$.

The survey activities reported were competently executed but the survey perspective was based on small area activity considerations. Measurements for this data set were specifically targeted to be within sub-divisions being built on reclaimed (suspect) land.

Prior Baseline Radiological Surveys

Florida Statewide Radiation Study (Publication No. 05-029-057, 12/87)

- In 1986-87, this study was conducted by GEOMET Technologies, Inc. under contract to the Florida Institute for Phosphate Research.
- Well over 6,000 Florida homes were surveyed for indoor radon concentrations. Homes in every county in the state were included.
- In half the homes, radon gas in soil and gamma radiation levels both indoors and out were measured.
- Besides new measurements, historical data (which includes the NURE data and the EPA's report entitled "Indoor Radiation Exposure Due to Radium-226 in Florida Phosphate Lands") were compiled and assessed.
- The study found that 7% of the state's land, located in 18 counties, showed definite evidence of elevated radon potential. Also, limited evidence of elevated levels were found in parts of an additional 14 counties.
- A preliminary review of this report was conducted and the report was found to be very informative. The data helps to reinforce the selection of the survey areas-of-interest for the proposed Pilot Study.

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The other set of data (FIPR 1986/1987) was carefully based on distributed sampling within population and political boundaries. It indicated only one area within the entire state of Florida where exposure rates exceeded the 20 $\mu\text{R}/\text{h}$ action threshold.

The survey activities reported were competently executed but the survey perspective was essentially based on uniform distribution considerations. This data set utilized approximately 6000 measurements to characterize the approximately 54,000 square miles of land area in Florida. On the average, then, one measurement represented a 9 square-mile ($\sim 5,700$ acre) area.

Prior Baseline Radiological Surveys

Use of Legacy Baseline Radiological Data

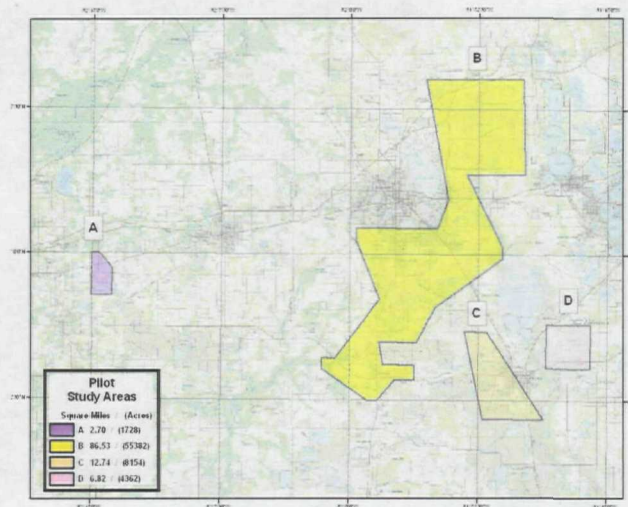
- Useful in providing an indication of the exposure levels to be expected in any regional suspect areas-of-interest.
- Will aid in the selection and bounding of any new aerial and detailed ground-based radiological surveys.
- Due to the age of the data and the density of the sampling employed:
 - Areas previously sampled may have been drastically altered due to recent population growth and building construction. Thus, the reliability of the old data is reduced.
 - Previous areas not sampled, but which have a potential radon problem, may go undetected.
- Hence, new measurements (aerial and ground-based) should be made in order to obtain a more accurate overview of any and all potential radon problem areas. This new data will limit the size of any remediation work to be conducted.

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Proposed Pilot Study Aerial Radiological Survey Sites



- 4 Survey Areas – 108.8 mi² (~ 69,600 acres)
- Bell-412 Helicopter with twelve 16-x 4-x 2-in. NaI(Tl) log detectors
- Survey Parameters
 - Altitude: 150 feet
 - Line Spacing: 250 feet
 - Ground Speed: 80 knots
- Total # Flights: 23 (58 flight hours)
- Total # Field Days: 21 (includes deploy/return legs and weather permitting)

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Proposed Pilot Study Aerial Radiological Survey Estimates

Study areas are located in Hillsborough and Polk County, Florida

Survey Size: 108.8 mi² or 69,600 acres.

Is to be flown at a survey altitude of 150 ft AGL and line spacing of 250 ft, approximately 595 survey lines, and at a ground speed of 80 knots (135 ft/sec).

Survey will take approximately 23 flights to fly, each flight is ~ 2.5 hours, totaling 58 flight hours. This includes flying the reconnaissance flight, altitude spiral, perimeter, land/water test lines, and survey lines.

Schedule Breakdown:

- Ground-team deployment to site: 2 days (one way)
- Helicopter ferry to site: 7 flight hours (one way)
- Field Collection: 15 days (work 6-days per week; 10-hours per day)
- Field Office Setup/Breakdown: 2 days total
- Estimated total time in field, weather permitting, is 21 days.

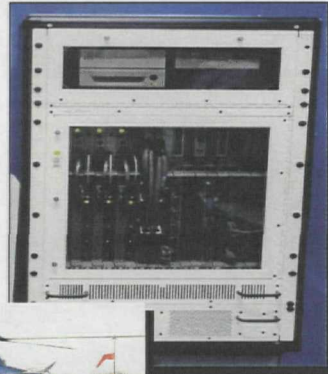
Mission Equipment – Data Recording

REDAR V (Radiation and Environmental Data Acquisition and Recorder System)

- Multi-processor data acquisition system custom designed by the RSL
- Displays radiation and positional information in real-time
- Archival gamma-ray spectra, aircraft position, meteorological parameters, and real-time clock

Sodium Iodide (NaI[Tl]) Detector Pods

- Contain 12 detectors 16- x 4 x 2-inch log-type thallium-activated sodium iodide scintillation detectors
- Output is full-energy spectra collected each second



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Mission Equipment

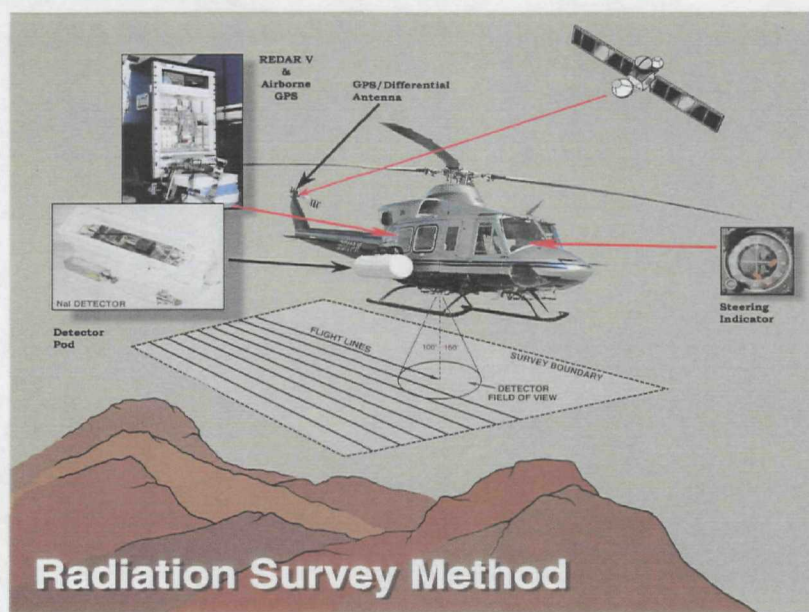
The principal equipment used on the helicopter mission is the REDAR V data acquisition system and the two pods of sodium iodide (NaI) log detectors. By using 12 detectors, the system has a sensitivity able to detect changes between as little as 5% variation in the background levels down to variations as low as 1 to 2 $\mu\text{R/h}$.

For comparison, other commercial background aerial surveying systems currently available routinely carry only a maximum of 4 log detectors.

The output of the twelve detectors is processed by four ADCs in the REDAR and recorded on the internal disk each second. The use of four ADCs allows the system to simultaneously record data from all 12 detectors and from a single detector for wide dynamic range.

The full energy spectrum is recorded for each ADC. This allows significant post-flight data processing capabilities.

Another option includes the use of a germanium detector in the tail cargo area.



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The AMS helicopter mission provides data that is key to understanding and documenting the public health and environmental impacts. [Our data will go to court!] The Data Products are key to detecting changing conditions, so that ground-based survey plans can be made and ultimately the clean-up efforts can be successfully documented.

Survey Method

Typically a 2.5-hour flight - Data flights are conducted as low as is safe to fly.

Typical surveys are flown between 150 to 500 feet above ground level (AGL).

Very high sensitivity – able to detect changes of a few $\mu\text{R/h}$ in exposure rate

Carries twelve 16"x4"x2" NaI log detectors – For comparison, commercial background aerial surveying systems routinely only carry a maximum of 4 log detectors

Differential Global Positioning System used to track survey and provide steering

Parallel lines are preferred for nearly every scenario, but other flight patterns can be accommodated.

Usually require ground truth to calibrate absolute exposure rate.

Data Products

All Data Available in GIS Format

Terrestrial Exposure Rate (all gamma radiation originating from the ground)

Man-Made Exposure Rate (as above, but with the removal of the spatially variable natural background component)

Specific Isotope Activity Plot (the distribution of a single radioactive isotope)

AMS Aerial Survey Sensitivity ^{a,b}

Altitude (feet)	Point Source Minimum Detectable Activity (MDA) ^c		Uniform Soil ^d (pCi/g)	Surface Deposition ($\mu\text{Ci}/\text{m}^2$)
	No Offset (mCi)	Midway (mCi)		
150	1.7	4.9	1.5	0.33
500	28.0	120.0	3.0	0.66

^a Twelve 16- x 4- x 2-in. NaI (TI) detectors; Line spacing equals to 2 x Altitude

^b Ra-226 MDAs based on the detection of Bi-214 in assumed equilibrium with parent Ra-226.

^c Amount detected within detector's field of view, whose radius is approximately the altitude. "No Offset" refers to flying directly over the source, whereas "Midway" equates to a lateral displacement equal to the altitude.

^d Other depth profiles generally have greater sensitivity, but overburden will hamper sensitivity.

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Aerial Survey Sensitivity:

This slide shows the sensitivity differences for a point source, uniform distributed source, and surface deposition distributed source for two typical survey flight altitudes:

MDAs are based on the detection of the Bi-214 (1764 keV) in assumed equilibrium with its parent Ra-226.

An altitude of **150 ft AGL**:

- Field-of-view of 6570 m² (1.6 acres)
- Ra-226 MDA of 1.5 pCi/g.
- Using a line spacing of 250 ft and at a ground speed of 80 knots (135 ft/sec), the helicopter can survey ~ 4 mi²/h.

An altitude of **500 ft AGL**:

- Field-of-view of 72,970 m² (18.0 acres)
- Ra-226 MDA (based on Bi-214) of 3.0 pCi/g.
- Using a line spacing of 1000 ft and at a ground speed of 80 knots (135 ft/sec), the helicopter can survey ~ 15 mi²/h.

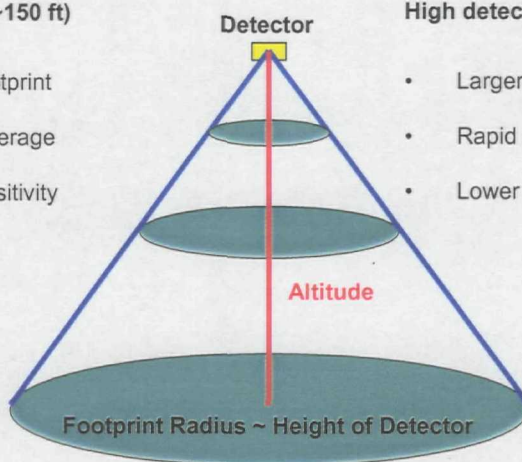
Weakness: Aerial surveys in general suffer from a large area averaging effect. MDA determination is dependent on several unknowns: soil density and moisture content, soil permeability, source distribution type, *etc.*, which can only be ascertain through extensive ground-based soil sampling.

AMS**Altitude Considerations****Low detector (~150 ft)**

- Smaller footprint
- Slower coverage
- Higher sensitivity

High detector (~500 ft)

- Larger footprint
- Rapid coverage
- Lower sensitivity



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Altitude Trade-offs

Low altitude brings the benefits of smaller footprint (better spatial resolution) and lower minimum detectable activities (MDAs) (better sensitivity).

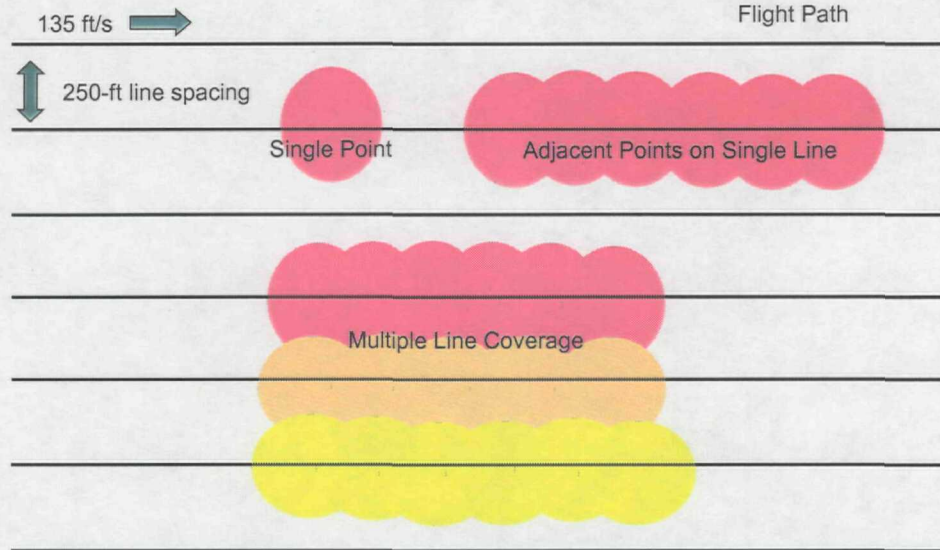
The lower the detector, the smaller the footprint.

Then either slow coverage of survey area, or discrete sampling (incomplete coverage).

Rule-of-Thumb for Field-of-View:

The Diameter $\sim 2 \times$ Height equation is a rough approximation.

Aerial Footprint



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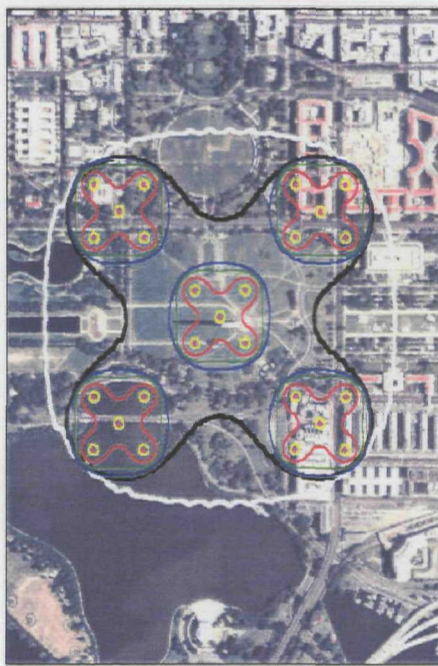
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Aerial Footprint Considerations

In this slide, we can perceive the effects of flying the helicopter at slower speeds and closer line spacing. The slower we travel and the closer the line space interval, the more overlap in the data being collected which results in an overall better and fuller (100%) area of coverage.

As was stated earlier, flying at a low altitude brings the benefits of a smaller footprint (better spatial resolution) and better sensitivity (lower MDAs).

The general rule-of-thumb for the AMS field-of-view (FOV) diameter is $\sim 2 \times \text{Altitude}$. Therefore for an altitude of 150-ft, the rule-of-thumb yields a FOV diameter of 300 ft or a radius of 150 ft, as shown. Thus as can be depicted in the figure, flying a line spacing of 250-ft would result in some overlap coverage of the area for multiple flight line passes.



AMS Helicopter Sensitivity & Resolution Model of 25 ¹³⁷Cs sources

KEY	Altitude (ft)	MDA ^a	Exposure Rate ^{b,c}	
White	3000	281 Ci	107 R/h	Lethal in 3 hours
Black	1000	82 mCi	30 mR/h	Health effects in a month
Blue	500	8 mCi	3 mR/h	1.2 X occupational limit
Green	300	2 mCi	0.8 mR/h	0.3 X occupational limit
Red	150	300 µCi	115 µR/h	19X background
Yellow	50	30 µCi	12 µR/h	2X background

^a MDA for a single point source (not array element)

^b Exposure rate at one-meter for a single source at the MDA limit

^c Background is 6 µR/h for these calculations

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Model of AMS Response (illustrates all effects)

Assumed 25 cesium-137 radioactive point sources are scattered in the Washington D.C. area

Don't know: where, physical form, quantity or kind of source

Higher altitudes (> 1000 ft) see only a blob (know approximate location, quantity is large)

Lower altitudes - sees not just blob, but clusters of sources

Helicopter low altitude flights (300 to 500 ft) can see 5 distinct clusters

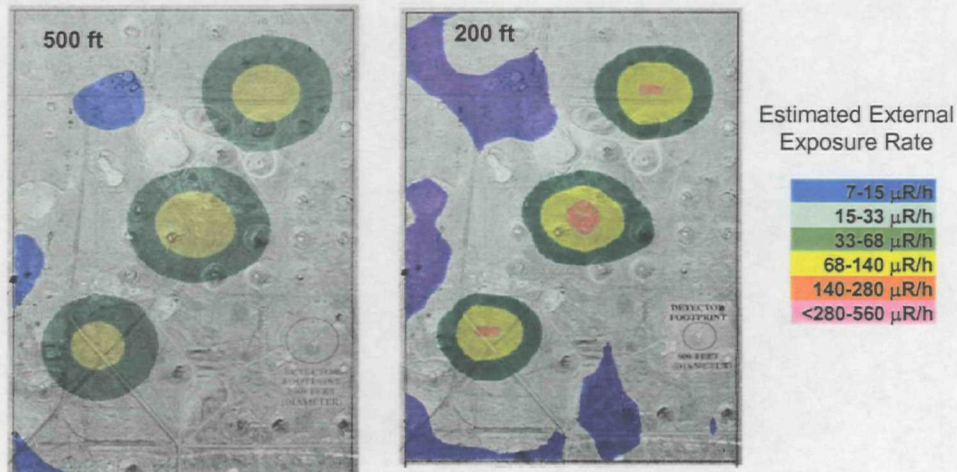
Lowest altitudes (50 to 150 ft) – helicopter can see each cluster as 5 distinct points

Note sensitivity limitation – highest altitudes detect only enormous-size sources. Thus, it would only be adequate for detecting immediate health threats.

Helicopter lower altitudes can locate and identify amount even if not a health threat but still media sensation (Weapon of Mass Destruction [WMD]).

AMS Aerial Sensitivity

Effect of Altitude – Nevada Test Site Area 3



As the platform goes higher, the ability to detect deviations from the dominant background decreases.
Spatial resolution also decreases with altitude.

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This is a visual presentation of the effect of altitude which emphasizes the need for the helicopter capability.

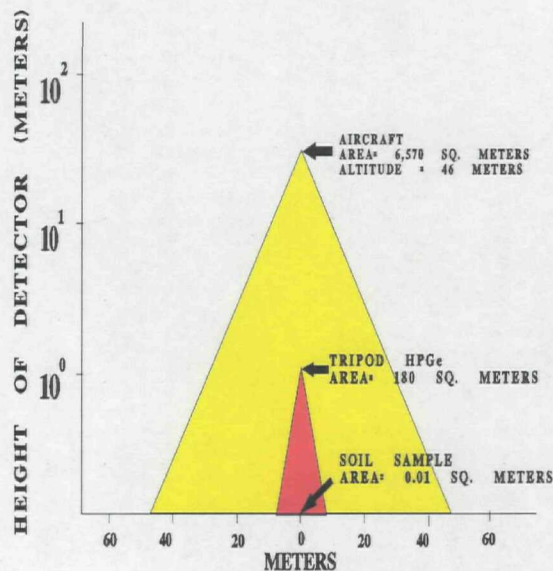
(Two data sets: helicopter at 500 feet and 200 feet AGL altitudes.)

Note 1: Notice the increased spatial resolution as the altitude of the detectors is decreased.

Note 2: Notice the loss of detectability as the altitude of the detectors is increased.

Note 3: Notice that at higher altitudes, the detectors view a large area with each measurement and the small-area, high-activity features are lost. (Detector footprint reference circle is located near the bottom right-hand corner of each plot.)

Detector Field-of-View Comparisons



For comparison, this slide shows the field-of-view (FOV) or area of coverage for three types of field measurements.

- **Aerial Survey** – flown at an altitude of 46 meters (150 ft)
 - FOV of 6570 m² (1.6 acres);
 - Ra-226 MDA = 1.5 pCi/g (based on Bi-214)
- **In Situ (Ground-Based) Measurement** – 60% n-type high resolution germanium (HPGe) detector (and/or a pressurized ionization chamber) mounted at a height of 1-m (3.3 ft)
 - FOV of 180 m² (0.05 acres)
 - Ra-226 MDA = 0.2 pCi/g (based on Bi-214, 15-minute sampling time)
- **Surface Area Deposition Soil Sample** – taken at a depth of 2.5 to 10.0 cm (1- to 4-inches)
 - FOV of 0.01 m² (2.4E-06 acre). Very, very small sampling area!
 - Ra-226 MDA = 1.0 pCi/g (True -- no daughters measured)

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This slide depicts the field-of-view (FOV) or area of coverage for three types of field measurements.

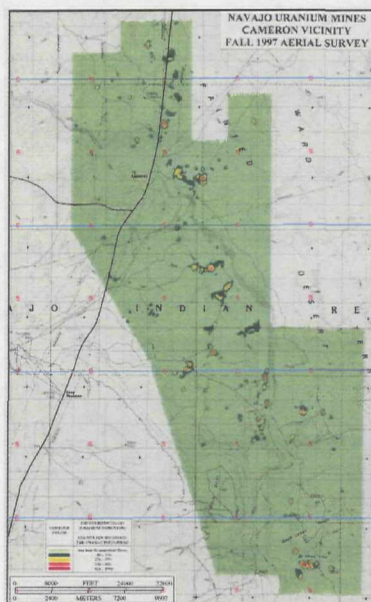
• **Aerial Survey:** Ra-226 MDA is based on the detection of the Bi-214 (1764-keV photopeak) in assumed equilibrium with its parent Ra-226. Preferred method for sampling large areas in the shortest amount of time. *Strengths:* 100% of the land area is uniformly characterized in the most cost effective manner. *Weakness:* Large area averaging effect. MDA determination is dependent on several unknowns: soil density and moisture content, soil permeability, source distribution type, *etc.* which can only be ascertain through extensive ground-based soil sampling.

• **In Situ (Ground-Based) Measurements:** Two measurements are made at each location -- both instruments are mounted onto a 1-m tall tripod and the data collected over a 15-minute period. *Strength:* By far the most precise measurement for acquiring the exposure rate at the detector location. *Weakness:* Although it has a smaller footprint than the aerial survey, it shares the same limitations as the aerial survey in terms of area averaging and MDA determination. Also, it can miss significant activity by the choice of random sample locations.

• **Mobile Ground-based Measurements:** Instruments mounted onto the sides (sideward looking detector array) or the rear (downward looking detector array) of a vehicle, dependent on the terrain/area to be measured. *Strength:* Good sampling density, coverage, and speed in the vicinity of likely human presence. *Weakness:* For sideward-looking array has poor sensitivity for long distances from the vehicle/road. Exposure rates measured from the roadway may vary slightly from the exposure rates measured inside of a house due to construction characteristics.

• **Surface Area Deposition Soil Sample:** Soil sample size 10 cm x 10 cm area, generally 2.5 to 10.0 cm in depth. Can be deeper if leaching is of major concern. *Strength:* Simply by counting longer, eventually able to acquire better statistics for the most precise measurements of radiation and isotopic concentrations. For Ra-226, analytical laboratory techniques can measure Ra-226 directly, not daughter products. *Weakness:* Very highly localized. Can miss significant activity by the choice of random sample locations. Particularly non-representative in disturbed soils.

Sampling Density Considerations



- The radiation contour map is from the aerial survey data collected during the 1994-1999 Navajo Uranium Mines Survey. Collection was at an altitude of 150 feet AGL and 300 feet line spacing.
- Red **S** symbols (at the nominal 3-mile sample spacing of the ground data taken by the 1986-1987 FIPR Florida survey) are overlaid on the Navajo data to estimate adequacy of the FIPR sample spacing for detecting small areas of elevated activity.
- Blue lines representing nominal NURE flight lines (6 mile spacing) are also placed on the figure for reference.
- If Florida mine activity is primarily from relatively small areas (like Navajo), FIPR data would not find/or properly characterize many impacted areas. This is probably why FIPR data disagrees with the higher activity levels found in the 1970s-1990s sub-division measurements made within known impacted areas. Because the NURE aerial data is integrated/summed every 250 feet along the flight path, the NURE data would be more likely than FIPR to see areas of elevated activity.

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CONSIDERATIONS FOR SMALL AREAS OF ELEVATED ACTIVITY AND FOR RELATIVELY UNIFORM DISTRIBUTIONS

“Scanning surveys are typically used to identify small areas of elevated activity. [MARSSIM]”

“In general, scanning the entire survey unit is less expensive than finding areas of elevated activity later in the survey process. Finding such areas will lead to performing additional surveys due to survey unit misclassification. [MARSSIM]”

If small areas of elevated activity are absent, relatively uniform distributions can be characterized by wide spaced samples rather than scanning.

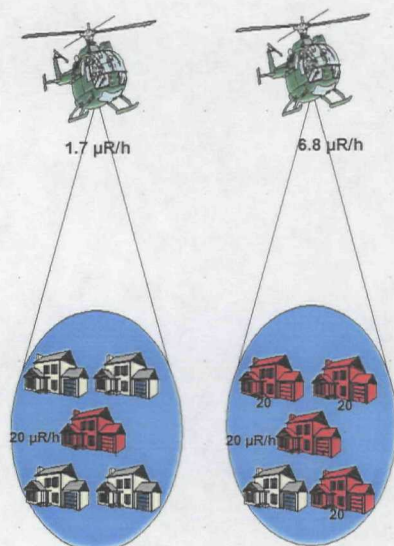
While the detailed distribution of activity in Florida is not presently known, existing Florida data and data from a similar survey series suggests that the distribution is probably more nearly represented by small areas of elevated activity rather than uniform distributions of small variability.

As previously noted, there are two Florida data sets which seem to support the small area hypothesis. One survey set (FIPR 1986/1987), was carefully based on distributed sampling within population and political boundaries. It indicated only one area within the entire state of Florida where exposure rates exceeded the 20 $\mu\text{R/h}$ action threshold. The other data set (numerous agencies 70s through 90s), consisting of targeted measurements made in relatively small sub-divisions, indicated levels often exceeding 50 $\mu\text{R/h}$.

Both survey activities were competently executed but the perspective was very different, the first essentially based on uniform distribution considerations, the second based on small area activity considerations. The first set utilized approximately 6000 measurements to characterize the approximately 54,000 square miles of land area in Florida. On the average, then, one measurement represented a 9 square mile area. Measurements for the second data set were specifically targeted to be within sub-divisions being built on reclaimed (suspect) land.

From 1994 through 1999, extensive aerial surveys were conducted throughout the Navajo Nation in areas of uranium mining activities. These mining activities closely resemble those conducted in Florida. The figure presents aerial (scanned) data acquired at one of the Navajo areas. The red “S” characters overlaying the aerial data show the nominal sampling interval of the 1986/1987 data taken in Florida. If the Florida distributions of activity look anything at all like the Navajo distribution, it is easy to see why the two existing surveys and a scan survey could give markedly different results. Each ground point of the existing surveys could be extremely accurate and representative of the activity at the measured point while giving almost no information about contamination within other areas of interest.

AMS Area Averaging Effect



- Residential Home Site Area is ~ 0.3 acres
- AMS helicopter, flying at an altitude of 150 ft, has a footprint of ~ 1.6 acres. However, the effective field-of-view of the AMS radiation detection system is also dependent on the isotope-of-interest's photopeak gamma energy and its air mass attenuation. Hence, the actual field-of-view is somewhat larger than stated.
- As demonstrated, the area averaging effect yields an inferred aerial exposure rate approximately equal to a factor of 12 less than the actual exposure rates observed on the ground.
- For Ra-226 (specifically Bi-214) flying at an altitude of 150 ft, the minimum detectable activity (MDA) for the AMS radiation detection system is ~ 2.5 µR/h.

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AMS Area Averaging Effect

Assumptions:

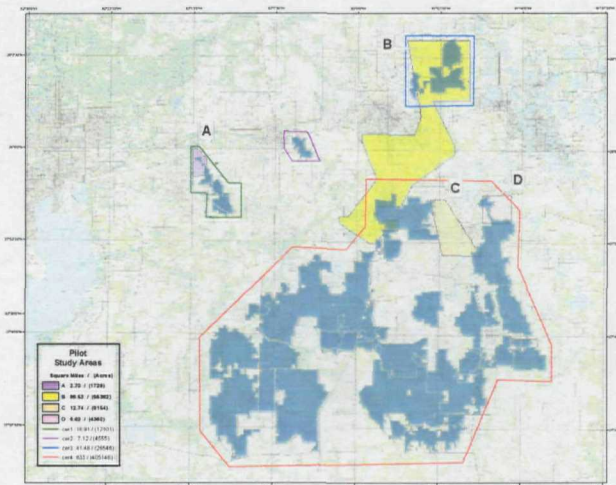
- Residential home site area is approximately 0.3 acres
- Survey flown at an altitude of 150-ft AGL, 250-ft line spacing and a ground speed of 80 knots resulting in a field-of-view (FOV) of 1.6 acres [$\pi * \{ \text{Altitude} / (5280 \text{ ft/mi}) \}^2 * 640 \text{ acres/mi}^2$]
- Ra-226 detection is based on the detection of Bi-214 (1764 keV) in assumed equilibrium with its parent Ra-226.

If only one house with an observable/actual exposure rate of 20 µR/h resided within the AMS FOV, the area averaging effect of the AMS data collection system would result in an increase to the overall background by 1.7 µR/h, which is factor of about 12 less than the actual exposure rate and below the AMS MDA of 2.5 µR/h. Hence, a single house would not be detected.

If two or more houses each with an actual exposure rate of 20 µR/h resided within the AMS FOV, each house would contribute 1.7 µR/h to the overall increase in the background. For the 4-house example, this would result in an overall increase of 6.8 µR/h, which is detectable.

NOTE: In order for the reading at the helicopter to be 20 µR/h, the entire area within its FOV must be homogeneous (*i.e.*, an infinite plane) reading 20 µR/h.

Florida Phosphate Mines CERCLIS Sites



- Four CERCLIS Survey Areas [outlined areas] 700.5 mi² (~ 448,350 acres)
- Bell-412 Helicopter with 12 16-x 4-x 2-in. NaI(Tl) log detectors
- Proposed Survey Parameters
 - Altitude: 150 feet
 - Line Spacing: 1000 feet
 - Ground Speed: 80 knots
- Total # Flights: 30 (75 flight hours)
- Total # Field Days: 18 (assume team already deployed in the field and weather permitting)

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CERCLIS Sites Aerial Radiological Survey Estimates

Study areas are located in Hillsborough and Polk County, Florida

Survey Size: 700.5 mi² or ~ 448,350 acres (areas enclosed by lines).

Is to be flown at a survey altitude of 150 ft AGL and line spacing of 1000 ft, approximately 228 survey lines, and at a ground speed of 80 knots (135 ft/sec).

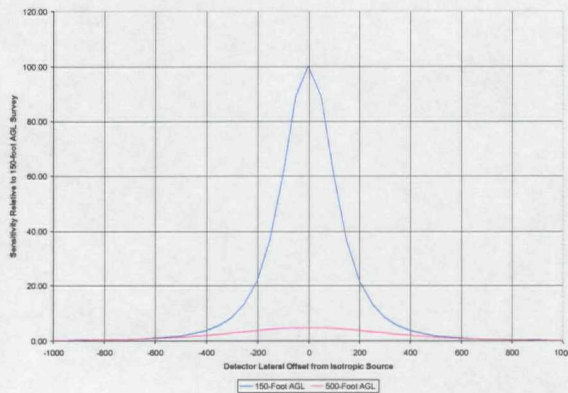
Survey will take approximately 30 flights to fly, each flight is ~ 2.5 hours, totaling 75 hrs. This includes flying the reconnaissance flight, land/water test lines, and survey lines.

Assumption: Survey team and equipment already in area. The field days cited do not include any contingency for weather, equipment problems, *etc* (typically add another 20%).

Schedule Breakdown:

- Field Collection: 18 days (work 6-days per week; 10-hours per day)

AMS Detector Relative Sensitivity Comparison



Comparison of the relative sensitivity of the AMS radiation detection system at two survey altitudes – 150-ft and 500-ft above ground level (AGL)

- Typical Survey Line Space is 2 x Altitude
 - 300 feet for 150-ft AGL survey
 - 1000 feet for 500-ft AGL survey
- For an isotropic source, a 150-ft AGL survey would have equal to or superior sensitivity than a 500-ft AGL survey for lateral offsets up to 500 ft (*i.e.*, 1000 ft line spacing) due to the sideward-looking portion of the detector array.
- Hence, BN recommends flying the proposed CERCLIS sites at an altitude of 150-feet using a line spacing of 1000 feet.

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AMS Detector Relative Sensitivity Comparison

This slide compares the altitude-related sensitivities of the AMS detection system contributions from both the down- and side-looking active areas of the NaI detector pods.

The sensitivity of a detection system to an isotropic point source is proportional to the effective (exposed) area of the detector and inversely proportional to the square of the slant range from the source. The effective area of a detector consists of both the down-looking and side-looking areas of the detector.

At zero lateral offset, only the down-looking area is seen by the source and the sensitivity reduction will be essentially that from the inverse square ratio of the altitudes. Thus, the 150 foot survey will have $(500/150)^2 = 11$ times the sensitivity of a 500 foot survey at zero lateral offset.

At large lateral offsets, the detector side area dominates the down area. However, for any offset greater than zero, in addition to the dominating side area, a larger effective down-looking area will always be seen at 500 foot altitude than at 150 foot altitude. Since the slant range correction for both altitudes converges at large offsets, a 500 foot altitude survey eventually has slightly more sensitivity than the 150 foot.

For the RSL detector system, the slant range/effective area crossover occurs at a lateral offset of ~500 feet. Therefore, up to 500 foot lateral offset (1000 foot line spacing), the 150 foot survey will have sensitivity equal to or superior than that of a 500 foot survey.

It is recommended that the CERCLIS areas be flown at 150 foot altitude and 1000 foot line spacing. The net result of such a survey is that 25% of the area will have the full sensitivity and spatial resolution of the detailed survey (150 ft altitude, 250 ft line spacing), and that the remaining 75% will have sensitivity as good as or superior to that of a 500 foot survey.